January 19, 1865.

Sir HENRY HOLLAND, Bart., Vice-President, in the Chair.

The following communications were read:—

I. "On Bubbles." By FREDERICK GUTHRIE, Esq., Professor of Chemistry and Physics at the Royal College, Mauritius. Communicated by Professor STOKES, Sec. R.S. Received December 22, 1864.

As it was found necessary, in considering drops*, to define the term, and limit its application, so we must understand once for all in what sense and under what restrictions the term bubble is to be employed. This is the more necessary, because the word bubble is used even more loosely than the word drop. In Plate I. fig. A, 1, 2, and 3 show the meaning of a drop as we have defined and used the expression; 4 shows the condition of a bubble as it is understood in the following investigation.

Under this limitation, a bubble XGL† only differs from a drop $XL_2\ L_1$ (3, fig. A) in consisting of a gas instead of a liquid. A bubble is a mass of gaseous matter compelled to assume a more or less spherical form by the cohesion and weight of the liquid medium in which it is formed, and separated from other matter by the action of gravity. Since, under like conditions of pressure, all gases are lighter than all liquids, the separating force is the gravity of the medium, as was the case with the drop (3, fig. A). Accordingly, a bubble invariably ascends. Owing to the universal diffusion of gases, no case can exist of a gas-bubble in a gaseous medium (XGG); and for obvious reasons a solid medium is inadmissible. So defined, a bubble must therefore invariably be a case of XGL.

It is, however, worth while, in passing, to notice the construction of some other bodies which are also called drops and bubbles. Thus all the states of matter shown in fig. B are called, in common speech, drops or bubbles; and some of them, indeed, are one or the other, according to the aspect in which they are viewed. All of the ten modifications in fig. B are very common: the Nos. 1, 2, 3, 4, 5, 6 are usually called drops; the Nos. 7, 8, 9, 10 are called bubbles. Nos. 4 and 5 show the two instances of what is called spheroidal state. Nos. 7, 8, 9, 10 are the commonest forms of the soap-bubble. The equations under each figure show the possible identity of two matters of the same kind. All the above ten cases are at once distinguishable from the true drop and bubble by the existence in them of an additional factor, which is not present in the true drop or bubble, namely the cohesion of a *film*. Such drops and bubbles may therefore be conveniently distinguished from the true ones of fig. A by being called *film-drops* and *film-bubbles*. In the spurious drops 1, 2, 3, 5, the film partly enclosing and restraining the drop is a film of liquid: so also in the bubble

* See the author's Memoir on Drops, Proceedings, vol. xiii. p. 444.

† Where X is either solid, liquid, or gaseous.

Fig. A

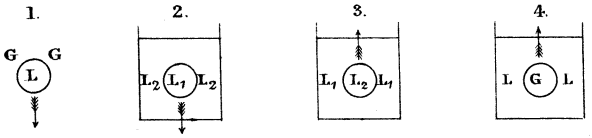


Fig. B.

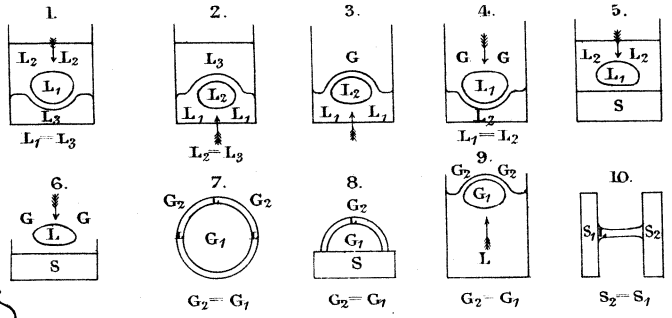


Fig. C.

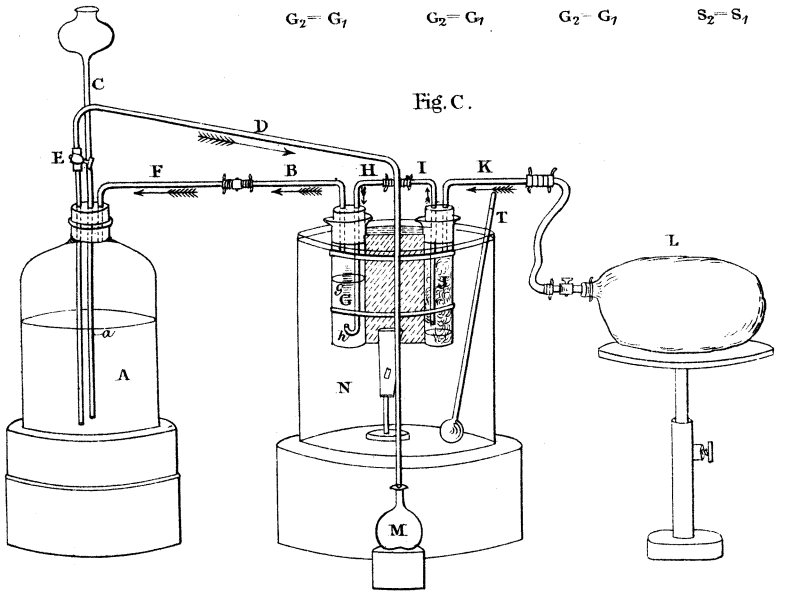
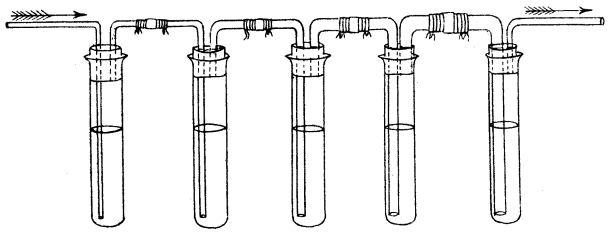


Fig. D.



9. In the drops 4, 6, and in the bubbles 7, 8, the restraining film is a gas. There is a remarkable inverse analogy between the cases 4 and 9. In 4 a gaseous film hinders a liquid from reaching a liquid; in 9 a liquid film hinders a gas from reaching a gas. The cases 7 and 10 are also called bubbles, although their only title to the name is the liquid film in each. Viewed as film-envelopes, 1, 2, 3, 4, 5, 6 are bubbles; viewed as spheroidal liquid masses they are drops.

Further, the spurious drops and bubbles differ from the true ones which we have to examine in a very important particular. The spurious ones are essentially statical phenomena, and retain their indefinite size for an indefinite time. The true drops and bubbles, on the other hand, grow until their exact equilibrium is established, and they acquire their definite size at the instant of the overbalancing of that equilibrium—that is, at the instant of their motion. It is, in fact, this overbalancing which determines the definiteness of their size, by withdrawing them from the size-determining effect of the action of the contending forces which accompany and condition their growth.

All attempts to get a perfectly uniform succession of bubbles of the pure form SGL (corresponding to water dropping from a glass sphere) failed through the impossibility of getting the immersed solid protected by the gas from the adhesion of the liquid. But by a contrivance similar to that described in the case SL_1L_2, where L_1 was lighter than L_2*, it was found possible to get bubbles of uniform size, and to measure them.

The most obvious manner of doing this is to force a gas at a fixed rate through an ordinary gas-delivery tube, and to collect and measure a given number of the bubbles in a calibrated tube over the pneumatic trough. This plan, however, is open to the objection of requiring a large quantity of liquid medium.

The apparatus employed is seen in fig. C. The quart bottle A is filled a little above the mark *a* with water, which is in some experiments covered with a film of oil. Through its cork three tubes, C, D, F, pass absolutely air-tight. The tube C is a simple funnel-tube, open near the bottom of A. The tube D also reaches to the bottom of A, and acts as a siphon: its longer limb is narrowed at the point, and delivers its water into the little flask M, whose neck bears a mark *m*. The shorter limb of D bears a cock E to regulate its discharge. The third tube F, which opens immediately under the cork of A, is fastened by a caoutchouc joint to the tube B. In this joint, and pressing the ends of both tubes, is a compact mass of cotton-wool. B passes through the cork of the little test-tube G, which is divided into millimetres, and contains the liquid through which the bubbles are to pass. Through the cork of G another tube H is passed, whose lower end *h* is bent out horizontally, and is beneath the surface of the liquid in G; H is connected by a caoutchouc joint with I, which passes nearly to the bottom of a second little test-tube J. The tube J contains a few drops of the liquid which is in G, and the space between I and

* On Drops, p. 478.

the sides of J is filled with cotton-wool moistened with the same liquid. The last tube K, which opens immediately under the cork of J, is either open to the air, or connected with a gas-bag containing the gas under examination, or fastened to a chloride-of-calcium tube, according to the requirements of the experiment. In some experiments the little tubes G and J are surrounded with water contained in the vessel N. The tubes G and J are firmly bound to a flat piece of cork held by the heavy clamp P, which rests on the bottom of N. A thermometer T is placed in the water of N.

The apparatus is used as follows:—B and F being disconnected, the bottle A is nearly filled through C. The end of F is closed by the finger, and, the stopcock E being opened, the siphon D is filled once for all by applying the mouth to its longer end. E being then closed, the tube G is filled up to the required mark with the liquid which is to serve as a bubble-medium. The cotton-wool in J is moistened with the same liquid. All the joints are made fast, and the tube K is connected with the gas-bag L. On turning the stopcock E, water flows through the siphon D into the flask M: to supply its place, gas must enter by F; that is, gas must bubble through the liquid in G. Before entering G it becomes saturated with the vapour of the same liquid in J. If all the joints are tight, it follows that the volume of water entering M is equal to the volume of gas which bubbles through the liquid in G. It is a sufficient test of the tightness of all the joints (as far as H), to run off a little water by D, so as to bring a bubble or two of gas through *h*, and to allow the apparatus to rest. If the tube H remains full of air to its extremity for a quarter of an hour, the apparatus may be considered as air-tight. A metronome is adjusted to beat to the required time. M is removed and emptied. E is turned till the bubbles, passing through the liquid in G, are synchronous with the beats of the metronome. This rate is maintained until the liquid in A sinks to *a*. The flask M is then put in its place, and from that instant the bubbles through G are counted. When M is filled exactly up to *m*, the experiment is finished. The proximity between M and G enables the eye to count the bubbles, and to watch without difficulty, at the same time, the rise of the liquid in M. The contents of M, divided by the number of bubbles, gives the mean volume of a single bubble. The use of the cotton-wool in the joint between B and F is to check the flow of gas through the apparatus. When this plug is absent, the considerable volume of gas in the upper part of A, being in direct communication with G, causes by its elasticity an irregular delivery of bubbles through G. Of course as M is filled the level of the liquid in A falls, the difference between the limbs of the siphon D is diminished, the flow through D is retarded, and the bubbles follow one another more slowly. We shall see, however, that the rate of sequence has exceedingly small, or absolutely no influence upon bubble-size. In the experiments actually performed to establish this fact, the metronome was allowed to continue beating throughout the experiment, and an occasional tap on the cock E was found sufficient to regulate the rate of sequence with perfect accuracy. The great comparative

volume of A, moreover, prevents the level of its water from undergoing more than a very slight variation during a single experiment.

Certain modifications were introduced in the apparatus for special purposes, which will be described in their proper places.

Judging by analogy from the results obtained with drops, we should conclude the bubble-size to be influenced mainly by

1. Rate of sequence, or value of gt.
2. Chemical nature of bubble-gas, if homogeneous. Proportion between its constituents, if heterogeneous.
3. Nature of solid from which the gas is delivered.
4. Size of orifice and geometric distribution of solid about its orifice.
5. Temperature of gas and medium.
6. Tension of gas, influenced by natural or artificial causes.
7. Chemical nature of liquid, if homogeneous; and proportion between its constituents, if heterogeneous.

As in the cases of SLG and SLL, the solid serves mainly as a support to the dropping liquid, and influences the size of the drop by the various ways in which it affects the liquid film which adheres to the solid; the actual disruption being between liquid and liquid: so in SGL the bubble parts in truth from gas.

The separation of a gas-bubble differs materially from that of a drop in this respect. In the case SLG it is the persistent cohesion of the liquid which gives the drop a spheroidal form, and thereby assists gravitation to overcome the stubborn cohesion of the liquid. In the case of SLL the separation is assisted by the persistent cohesion of the liquid medium, which also tends to mould the drop into a spherical form, and is hindered by the stubborn cohesion and weight of the medium, which, by resisting its descent, increases its weight. In the case of a bubble, the ascent of the bubble is due wholly to the descent of the liquid medium; and the spheroidal form of the bubble is due wholly to the persistent cohesion of the liquid medium; for this cohesion is most completely satisfied when the cavity containing the gas is most spherical.

We may now examine *seriatim* the influences of the seven conditions noticed above.

SGL.

Influence of rate.—To examine the effect of variation in gt we may take common air as the gas, distilled water as the liquid medium, the tube H of glass having an opening h of any convenient unmeasured size; and as we are not concerned with the absolute, but with the relative sizes of the bubbles, the vessel M may be of an indefinite size.

Table α shows the effect of variation in gt alone. Column 1 shows the values of gt. Column 2 the sequence of the experiments. Column 3 the number of bubbles. Column 4 the mean relative size of a single bubble at the respective rates of column 1.

TABLE α.

From glass, air-bubbles through water.

T=23° C.

B=767 millims.

1. *gt.*	2. Sequence of experiment.	3. Number of bubbles having together the volume M.	4. Relative mean volume of single bubble.
0·33	7	96	96·66
	8	97	
	9	97	
0·50	4	100	99·80
	5	99	
	6	100	
	16	100	
	17	100	
1·00	3	104	103·00
	10	103	
	11	103	
	19	103	
	2	103	
	14	102	
2·00	12	97	99·17
	13	98	
	15	98	
	18	98	
	20	103	
	21	101	
5·00	1	103	103·00

It would at first seem as though there were a well-marked difference depending upon the value of gt. But in this method of experimenting there is a possible maximum error of two bubbles in each case, or an error of four bubbles in the comparison of two instances. This nearly covers the observed discrepancy. To set this point at rest, experiments were made with a larger number of bubbles as follows. The vessel taken for M was a 100 cub. centims. flask. The water in A was each time filled up to a. Only those two of the values of gt which gave the most widely differing results in the preceding Table were reexamined, viz. $gt=0{\cdot}33$ and $gt=1{\cdot}00$. A thread was fastened to the end of the siphon D, so as to deliver its contents in a series of very rapid and minute drops.

TABLE β.

From glass, air-bubbles through water.

T=23° C.

B=767 millims.

gt.	Number of bubbles in 100 cub. centims.	Mean absolute volume of single bubble.
		cub. centim.
0·33	1970 1970	0·05076
1·00	1974 1972	0·05068

Hence, under these conditions, rate has little or no influence upon bubble-size. In order to see whether a tube of different calibre would give rise to bubbles more sensitive in regard to their rate, a narrower orifice at *h* was employed. The flask M had a capacity of 50 cub. centims. The following mean results were obtained, each mean being derived from two experiments:—

gt.	Number of bubbles in 50 cub. centims.	Absolute volume of single bubble.
		cub. centim.
0·33	1927	0·02595
1·00	1945	0·02571

This result, taken together with Tables α and β, shows how small is the effect of rate upon bubble-size. If anything, there is, on the whole, a very slight tendency to diminution in bubble-size as *gt* diminishes—that is, as the rate increases. This is just the reverse of what was found to be the case with SLG. Most probably, however, this effect is not due specifically to the rate, but to the alteration in the diameter of the orifice at different rates. When a rapidly succeeding series of bubbles passes through the orifice *h*, the sides of the delivery-tube are swept more completely dry than when the bubbles pass more slowly; so that in the former case the opening is, in fact, a little larger than in the latter. We shall see in the sequel how sensitive bubble-size is to variation in the width of the delivery-tube.

It may be here noticed that, unless the tube H remains strictly in the same position, it is hopeless to attempt to get uniformity in results. This is especially the case when the opening *h* is turned half up in the shape of a siphon; for then the least displacement out of the vertical causes virtually an alteration in the available size of the opening, and a consequent variation in bubble-size. A great and otherwise unaccountable variation in the bubble-number, under circumstances apparently identical, directed attention to this source of error. By taking a wider tube, and allowing the end to contract in the blowpipe flame, a rounded opening is produced, the horizontal projection of which is much less variable with alteration in the verticalness of the tube H.

The reason why bubbles are less sensitive to variations in gt than are drops is sufficiently obvious. In the case of SLG, variation in gt affects the size of a drop by varying the thickness of the liquid-film which covers the solid at the moment of the drop's separation. We have seen that when this film is thin, in consequence of slowness in the supply of liquid to the solid, the size of the drop is diminished, because the solid reclaims liquid from the drop-root at the instant of the latter's departure. But in the case of a bubble, at least in the arrangement of the above experiments, there is in all cases an indefinitely great aëriform residue, the separation of the bubble being determined by the superior density of the liquid medium, and by its persistent cohesion.

Rate being thus of no appreciable influence upon bubble-size, we are not compelled to take the same extreme precaution to ensure uniformity of gt, as was found necessary with drops.

Effect of change in the chemical nature of the bubble-gas.—The gases examined were hydrogen, oxygen, nitrogen, carbonic acid, and atmospheric air. Boiled water was left for several hours in the bags containing the gases, so that the gases might be perfectly saturated with water, and the water with the gases, and so that they might have the same temperature. This water was then employed to fill the vessel A. By this means all disagreement between the volume of the bubbles and the volume of the water flowing from D, caused by the solution of the gas in the water of A, is avoided. In each case the gas was allowed to bubble through G until the water in it was saturated.

The following Table shows the results obtained :—

Column 1. The gas employed.

Column 2. The number of bubbles having together the volume 50 cub. centims., each number being the mean of three experiments.

Column 3. The absolute mean volume of a single bubble.

TABLE γ.

M=50 cub. centims.
gt=0″·33.
T=24° C.
B=766 millims.

1. Bubble-gas.	2. Mean number of bubbles having the volume 50 cub. centims.	3. Absolute mean volume of single bubble.
		cub. centim.
Nitrogen	2173·0	0·023009
Air.....	2070·0	0·024154
Carbonic acid.....	2035·0	0·024570
Oxygen	2021·7	0·024731
Hydrogen	1981·3	0·025235

The chemical nature of the gas, therefore, has also very little influence upon bubble-size. The two purely physical influences active in determining the bubble-size are the density of the gas and its solubility in water. These act to produce opposite effects. Increase of density in the gas delays the departure of the bubble, and thereby increases its size; increase in the solubility of the gas in water impairs the stubborn cohesion of the water, and thereby diminishes the bubble-size. If p and q be the specific gravities of two gases P and Q referred to water, the buoyancy of two equal bubbles of them will be respectively

$$W - p\,W,$$

and $$W - q\,W,$$

where W is the weight of an equal volume of water; that is, $W(q-p)$ is the difference in buoyancy of the two bubbles. The gases arranged in their order of density are

$$CO_2,\ O,\ Air,\ N,\ H.$$

Arranged in order of solubility (at 20° C.),

$$CO_2,\ O,\ H,\ Air,\ N.$$

The properties density and solubility are of course incommensurable, so that we cannot predict the extent to which they may counteract one another in the same gas to determine its bubble-size. But the order of the gases in Table γ is quite consistent with our previous knowledge. Thus the bubble-size of air is intermediate between the bubble-sizes of nitrogen and oxygen. It would, however, at present be premature to attempt to make use of bubble-size to furnish an additional equation in gas-analysis.

Effect of temperature and of tension.—The first of these has also a twofold action, by changing the density of the gas, and by changing the cohesion of the liquid. Within a natural range of 10° C. change of temperature takes no appreciable effect upon bubble-size. Also a variation of three-quarters of an inch in the natural barometric mercurial column is without sensible influence. These two influences were not made matters of special study, but were only examined with the view of ensuring absence of error from other experiments.

Effect of change in the geometrical distribution of solid: size of orifice.—The change examined in this sense was the alteration in the size of the orifice through which the gas bubbled. For this purpose the ends of six tubes of various internal diameter were ground flat, and until they had exactly the same length. One end of each tube was stopped by a little glass disk covered with a film of wax. The tube was then filled to overflowing with distilled water, and another little disk was pressed on the top, the superfluous water being wiped off. The tube was then weighed, emptied, and dried and reweighed. The same being done for each tube, the volumes of the tubes are known to be in the same proportion as the weights of their liquid contents, the diameters or radii of the tubes being in the ratio of the square roots of the same weights. To calibrate tubes in this manner, water is to be preferred to mercury, because the latter leaves a film of air between itself and the glass, and thereby introduces a considerable error in the deduced calibre of very narrow tubes. The tubes were inserted

into the cork of the tube G, fig. A. The vessel M was a burette graduated into tenths of cubic centimetres. A hundred bubbles at $gt=2''\cdot0$ were allowed to pass through G, and the water from D was measured.

TABLE δ.

$gt=2''\cdot0$.

Relative areas of sections of tubes.	Mean volume of 100 bubbles.	Relative radii of tubes.	Actual observed volumes of 100 bubbles.	
	cub. centims.			
0·0204	3·5	0·1428	3·5	3·5
0·2112	14·9	0·4595	14·9	14·9
0·3642	15·2	0·60348	15·1	15·3
1·9880	17·8	1·4099	17·9	17·7
3·1002	24·4	1·7607	24·3	24·5
4·4094	31·9	2·0998	31·9	31·9

From this Table we see that the bubble-size is very sensitive to the size of the orifice. The bubble-size is doubled if the radius of the orifice is increased fivefold; and so on. The same effect can also be well shown in a manner quite analogous to that adopted * to show the effect of variation in radius of curvature of the solid (SLG).

If the same quantity of gas be made to bubble in succession through the same liquid, similarly disposed in similar vessels, and if the tubes through which it is delivered have continually decreasing diameters, then the rates of bubbling are seen to follow the inverse order of the diameters of the tubes. Fig. D shows such an arrangement, which requires no explanation. In fact the reason why increase in radius of curvature in the case SLG produces increase of drop-size is very similar to that which causes increase of orifice to increase bubble-size in the case SGL. In the former case the thickness and general approximation of the residual liquid-film to the drop is greatest in large and flat surfaces; in the latter the area of residual gas is larger when the orifice is larger. When, around a large orifice, the liquid medium closes upon the bubble, the latter is not so straitened for material as when the orifice is narrow.

The influence of the size of the tube upon bubble-size is of considerable practical importance. In washing a gas, in separating two gases from one another by a medium which absorbs one of them, in saturating a liquid by a gas (a process which so often occurs in manufactures and analysis), the completeness of the operation invariably depends upon the extent of surface in common between the gas and liquid during a given time. If a spherical bubble, having the volume V and the surface S, be divided into two equal spherical bubbles, each having the volume $\frac{V}{2}$ and the surface s, then

$$\frac{S}{2s}=\frac{1}{2^{\frac{1}{3}}}.$$

* On Drops, p. 460.

So that if the surface of the original bubble be 1, the surface of the two bubbles of half the size taken together is 1·259885. By making the gas-delivery-tube small, the absorbent surface of the same quantity of gas which passes through is increased in this manner, and the absorption is consequently more rapid or more complete.

Effect of change in the chemical nature of the liquid medium.—To examine this (perhaps the most interesting phase of the causes of variation in bubble-size), the gas-bag L was replaced by a chloride-of-calcium tube. The cotton-wool of J was saturated with the liquid, which was placed for examination in G; so that the bubbling gas was dry air already saturated with the vapour of the liquid through which it had to bubble. It is clear that if the air so charged were to come into contact with the water in A, the vapour would dissolve in the water, while the air would become moist; a difference in volume would be thereby occasioned, according to the difference of tension of the vapour of the liquid in G and J and that of water. To avoid this source of error, the vessel A was filled with mercury. After each experiment the vessel A was completely refilled with mercury, so as to expel the vapour of the liquid employed in the previous experiment. The mercury was then run off at D, until it fell in A nearly to the mark *a*. The liquid under examination in G had a height above *h* inversely as its specific gravity: this the graduation of the tube G made easy. By this means the pressure on the gas as it issued from *h* was the same in all the experiments. The vessels A, G, and J were all sunk in the same trough of water, so that the volume of the air should undergo no alteration from temperature, either during or after its passage through G. When *gt* had been brought exactly to 2″, and the mercury in A had sunk to *a*, a graduated burette was brought under the end of the siphon D, and kept there while 100 bubbles passed through G. The numbers of column 2 are each of them the mean of two determinations.

TABLE ε.

$gt=2''$.
T=25° C.
B=764 millims.

Liquid medium.	Mean absolute volume of 100 bubbles of air.
	cub. centims.
Mercury.....	41·2
Glycerine	11·45
Water.....	8·60
Butyric acid	5·82
Acetic acid.....	5·72
Alcohol	4·80
Benzol	4·80
Turpentol	4·53
Acetic ether	3·72

These liquids, which were purposely taken the same as those whose drop-sizes were examined, are arranged in Table ϵ in the order of the magnitude of the bubble-size. We see that the order is not the same in the two cases. The difference is due to the elimination in Table ϵ of the influence of gravitation. In fact the only forces which influence bubble-size, as shown in Table ϵ, are the retentive and stubborn cohesions of the liquid*; for the first of these seeks to diminish, the second to increase the bubble-size. If RC be the retentive, and SC the stubborn cohesion, the liquids are arranged in Table ϵ in the same order of magnitude as are the values of $\frac{SC}{RC}$. The density of a liquid seems therefore to vary with its stubborn rather than with its retentive cohesion; for there is an evident general tendency in the above Table ϵ for the liquids to arrange themselves in the order of their specific gravities. Water once more distinguishes itself, taking a higher place in the scale than its density would point to: this must arise either from its exceptionally great stubborn, or from its exceptionally small retentive cohesion.

Acetic ether and alcohol are also exceptional—the former taking a lower, the latter a higher place in the scale than would be the case if the same state of quantity of matter in a given space (which is usually measured by means of gravity) affected also the cohesion of the liquid so as alone to determine the bubble-size of a gas passing through it. Perhaps also the gas having different degrees of solubility in the different liquids may affect their cohesions unequally. This source of variation, however, is probably very small, as we have seen to be the case when the gas varies and the liquid remains the same. A few experiments with a mixture of benzol and turpentol, and with alcohol and water, showed that in all cases the mixed liquid gives rise to a bubble intermediate in size between those caused by the single liquids.

By measuring the volume of a greater number of bubbles, the actual differences of bubble-size due to various liquids would of course become more apparent.

Throughout the examination of drops and bubbles in the present and previous communications, I have sought to direct attention to the main influences which fix the size of a drop or bubble, rather than to pursue any one branch of the inquiry into its minute ramifications. Further, the subject has been treated wholly from a statical point of view; that is, the bubble and drop have been considered at that period of their being when the contending forces which act upon them have brought them into a state of unstable equilibrium or incipient motion. It is in fact only at this point, the instant of their ripeness, that they have a definite size; for their size increases until the contending forces themselves withdraw the drop or bubble from the sphere of the action which determines their volume.

Knowing now the direction and approximately the relative amounts of the effects due to the various conditions under which the drop and bubble

* For the meaning of these terms see Paper "On Drops," p. 469.

are formed, the most prolific field of inquiry is promised by the study of the drop- and bubble-size as a means of proximate chemical diagnosis*. It does not appear that bubble-volume is at present likely to afford an additional equation for gas-analysis; but we have seen that both drop-size and bubble-size may offer very valuable criteria as to the constitution of liquids. And although the former (drop-size), especially in the case SL_1L_2, is by far the most sensitive to variation in the chemical constitution and proportion of mixed constituents, the latter has the advantage of requiring a much less amount of liquid, and of being applicable to every liquid without regard to its solubility in other liquids.

II. "Note on the Invisible Radiation of the Electric Light." By JOHN TYNDALL, F.R.S. Received January 13, 1865.

Pending the preparation of my complete memoir, which may occupy me for some time to come, I would ask permission of the Royal Society to lay before the Fellows a brief and partial summary of the results of my experiments on the invisible radiation of the electric light.

The distribution of heat in the spectrum of the electric light was examined by means of the linear thermo-electric pile, applied to the solar spectrum by Melloni, Franz, Müller, and others. The electric spectrum was formed by lenses and prisms of pure rock-salt, its width being equal to the length of the row of elements forming the pile. The latter, standing at right angles to the length of the spectrum, was caused to pass through its various colours in succession, and to search the spaces beyond the region of colour, in both directions.

As in the case of the solar spectrum, the heat was found to augment from the violet to the red, while the maximum heating effect was observed beyond the red, and at a distance from the red, in one direction, equal to that of the green of the spectrum in the other.

The augmentation of temperature beyond the red in the case of the electric light is sudden and enormous. Plotting from a datum line the thermal intensity of the various portions of the spectrum, the ordinates suddenly increase in length beyond the red, reach a maximum, and then fall somewhat more suddenly on the other side. When the ends of the ordinates are united, the curve beyond the red rises in a steep and massive peak, which quite dwarfs the luminous portion of the spectrum.

The comparative height and steepness of this peak are much greater than those obtained by Professor Müller for the solar spectrum. Aqueous vapour acts powerfully upon the invisible rays; and doubtless the action of this substance in our atmosphere has toned down the eminence beyond the red in Professor Müller's diagram. A solar spectrum, produced beyond

* Some word is required to denote the acquirement of the knowledge of the constitution of a substance without taking it to pieces (analysis). "Diagnosis," used in its purely etymological sense, answers this purpose.